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Respectfully submitted,

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By George D. Sheehan
George D. Sheehan

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Piezoceramic multilayer actuator with a transistion
region between the active region and the inactive head
and foot regions

5 The invention concerns a piezoceramic multilayer
actuator according to the preamble of the first claim.

Multilayer actuators made from piezoceramic materials
have two-way contacting, that is to say the internal
10 electrodes are led out alternately at the surface of the
opposite sides of the actuator and each is electrically
connected in parallel at that point through an external
electrode. For electrical isolation, the head region and
the foot region consist of inactive, that is to say
15 electrode free layers of piezoceramic.

The shrinkage of the piezoceramic material, in
particular in the passive head and foot regions, is
influenced by the sintering process due to the
20 arrangement of the metallic electrodes and the layers of
piezoceramic material. Differences in shrinkage between
regions located close to electrodes and regions located
away from electrodes lead to stresses in the ceramic
material, which either cause cracks during the sintering
25 process or act to reduce the strength of the finished
component. As a result, the susceptibility of these
components to the formation of cracks during operation
is considerably increased. Different expansion
characteristics of the active and of the passive region
30 during operation lead to stresses which favour crack
formation, in particular at the boundary between the two
regions. Cracks can be tolerated in a few applications.
However, there are fundamental problems. If the actuator
is not completely encapsulated, electric fields occur at
35 the ends of the electrodes exposed by the cracks, which
can lead to the adsorption of water or other polar

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molecules. These cause leakage currents or lead to a serious degradation of the actuator performance. Also, it cannot be totally ruled out that the actuators fail during operation because of cavitation due to earlier
5 crack damage.

The object of the invention is to eliminate to a large degree the occurrence of crack-forming stresses.

- 10 This object is achieved by means of the characterising features of the first claim. Other advantageous developments of the invention are claimed in the sub-claims.
- 15 According to the invention, a transition region, whose shrinkage behaviour during manufacture and whose expansion behaviour during operation lies between the respective shrinkage or behaviour of the active region and the respective shrinkage or expansion behaviours of
20 the piezoelectrically inactive regions, is interposed between the active region and the inactive head and foot regions. This transition region can be created by two measures. The spacing between the inner electrodes and the actuator ends can either be increased from electrode
25 to electrode in the transition region, or the material of the transition region may consist of a piezoceramic material whose shrinkage and expansion behaviour lies between the properties of the active region and the properties of the passive region. The properties of the
30 material in the transition region, in particular its sinter characteristic, can be influenced by doping with impurity atoms. The materials of the inner electrodes are suitable for this purpose. The doping can be a concentration produced by natural diffusion in the
35 active region at the boundary between an inner electrode

and the ceramic material. Doping can be carried out with silver, for example, which is a material of the inner electrodes.

5 According to the invention, increasing the spacings of the inner electrodes in the transition region has the effect that during fabrication of a multilayer actuator, the different shrinkages between the active and the inactive regions do not occur abruptly thus crack
10 formation due to the build-up of stresses is avoided. When the operating voltage is applied during the operation of the actuator, the field strength in the transition region is gradually reduced to zero in accordance with the increase in the electrode spacing.
15 The stresses which would otherwise be produced by the differential expansion of the active region and the adjacent inactive region are distributed through the transition region within a much greater component volume. This prevents the stresses reaching a critical
20 magnitude which triggers crack formation. The increase in the spacings between the electrodes in the intermediate region can be produced by stacking a suitable number of films of piezoceramic material between the electrodes at the desired spacing, these
25 films not being printed with electrodes.

There are different ways of increasing the inner electrode-to-inner electrode spacing in the transition region. The spacing can be increased stepwise by the
30 natural scale progression. If, for example, the electrode spacing in the active region is 100 μm , which generally corresponds to the thickness of a layer of piezoceramic material together with the metallic material layer of the electrode, then the spacing in the

transition region is increased in steps of 200 μm , 300 μm , 400 μm , etc.

5 In a further development of the invention the electrode-to-electrode spacing can also be increased stepwise in the transition region in a geometric progression. Likewise, starting with a spacing of the inner electrodes of 100 μm , in this case the spacing increases in steps of 200 μm , 400 μm , 800 μm , etc.

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In the transition region, the spacing of the inner electrodes can also be effected stepwise in a logarithmic scale.

15 The invention is explained in further detail with the aid of exemplifying embodiments, wherein:

20 Figure 1 shows a multilayer actuator according to the invention, whose transition region is formed by increasing the spacing between the electrodes, and

25 Figure 2 shows a multilayer actuator according to the invention, whose transition region is formed by a piezoceramic material whose shrinkage and expansion behaviour lies between the properties of the active region and of the passive region.

30 A piezoceramic multilayer actuator 1 is shown schematically in a much enlarged form in Figure 1. The actuator has an alternating contact arrangement. It has been fabricated in a monolithic process, that is to say it consists of stacked thin layers 2 of
35 piezoelectrically active material, for example lead

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zirconate titanate (PZT), with conductive inner electrodes 3 disposed between said layers. Prior to sintering, the inner electrodes 3 are printed by a silk-screen process onto the piezoelectrically active layers 2, the so-called green films. The films 2 are pressed along with the inner electrodes 3 into a stack, pyrolyzed and then sintered, thereby producing a monolithic multilayer actuator 1.

10 The inner electrodes 3 are led out alternately to the opposite surfaces of the actuator, where they are interconnected by an outer electrode 4, 5. As a result, each of the inner electrodes 3 is electrically connected in parallel at one side of the actuator 1 and thus
15 combined in one group. The outer electrodes 4, 5 are the connecting poles of the actuator. If an electrical voltage is applied via the connections 6 to the connecting poles, then this electric voltage is transmitted in parallel to all inner electrodes 3 and
20 produces an electric field in all layers 2 of the active material, which is consequently mechanically deformed. The sum of all these mechanical deformations is available at the end faces of the actuator 1 as a useable expansion 7 and/or force.

25 A conventional multilayer actuator consists of the inactive head region 8 and the inactive foot region 9, in which no inner electrodes are disposed, and the active region 10 with the inner electrodes 3. In the
30 multilayer actuator 1 according to the invention, a transition region 11 is disposed between the electrode-free head region 8 and the electrode-free foot region 9 and the active region 10, respectively. Whereas the spacing 12 of the inner electrodes 3 in the active
35 region 10 is always identical, it increases from

state. The spacing 14 is twice that of the spacing 13 or the spacing 12, the spacing 15 is three times, the spacing 16 is four times and the spacing 17 is five times greater than the spacing 13. The increased
 5 spacing can be achieved by stacking a suitable number of layers 2 corresponding to the increased spacing.

The exemplifying embodiment of Figure 2 differs from the exemplifying embodiment of Figure 1 only in the transition region, which here is denoted by 18.
 10 Features corresponding to the previous exemplifying embodiment are denoted by the same reference numbers. The transition region 18 consists of a piezoceramic material whose shrinkage and expansion behaviour lies between the properties of the active region and the
 15 properties of the passive region. It is, for example, doped with silver, a material of the inner electrodes, in a concentration that is produced by natural diffusion in the active region at the boundary between an inner electrode and the ceramic material.

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Claims

1. Piezoceramic multilayer actuator (1) with inner electrodes (3) led out alternately at the actuator surface, wherein, for parallel connection, the inner electrodes (3) of identical polarity of the
 25 active region (10) are connected to the respective outer electrode (4, 5), the outer electrodes (4, 5) are disposed on opposite sides of the actuator (1), and the head region (8) and the foot region (9) are piezoelectrically inactive, **characterised**
 30 **in that** a transition region (11, 18) whose shrinkage and whose expansion behaviour lies between the shrinkage and the expansion behaviour of the active region (10) and the shrinkage and